BNL Neutron Detectors I Met

a few personal vignettes on occasion of the

Veljko Radeka Fest

December 9, 2010
Brookhaven National Laboratory

Dieter K. Schneider

with much help from Graham Smith and Neil Schaknowski

Neutron Detector R&D in Instrumentation

1970's: 20x20cm^2 detectors with global resistive charge division. Beginning of long-term collaboration with Benno Schoenborn and his Structural Biology group.

1980's: 20x20cm^2 detectors with multi-node, continuous interpolating resistive charge division, and analog centroid finding system.

50x50cm^2 detector for SANS.

1990's: Very high resolution detectors (5x5cm^2) with 400μm FWHM position resolution.

Suites of three 20x20cm^2 detectors for larger angular coverage

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1D and 2D position sensitive ionization chambers for new instruments at new user sources such as the Spallation Neutron source.

First Instrumentation Neutron Area Detector was Part of the Discoveries Leading to the Invention of Multilayer Monochromators

J.L. ALBERI VIII-37

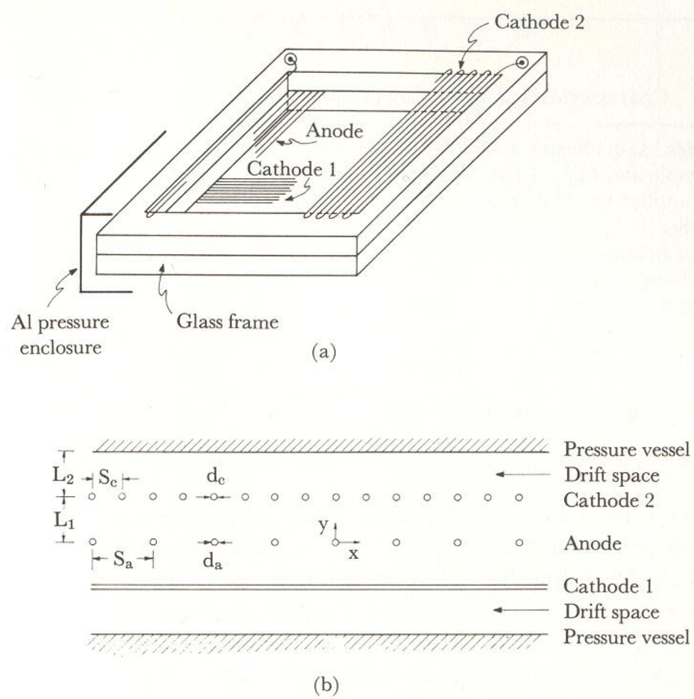
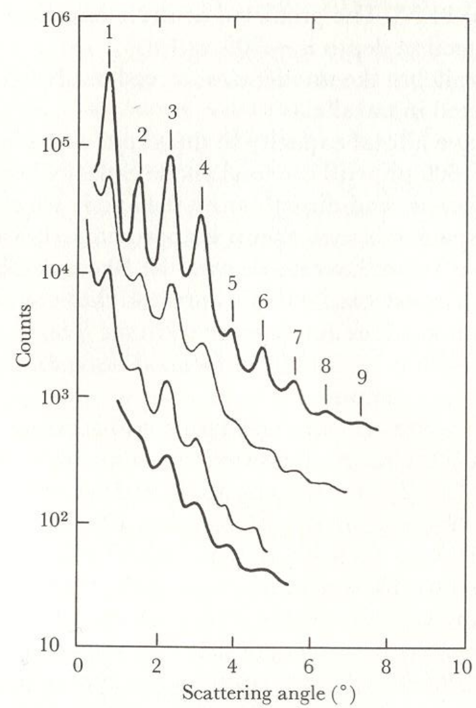


Figure 9. (*a*) Schematic diagram of multiwire proportional chamber geometry. (*b*) Schematic diagram showing parameters for the electric field calculation.

Brookhaven Symposia in Biology No 27 (1975)
Neutron Scattering for the Analysis of Biological Structures

- J.L. Alberi: Development of Large Area Position Sensitive Neutron Detectors; VIII-24
- D.L.D. Caspar and Walter C. Phillips: Dynamical Effects in Small-Angle Neutron Diffraction From Membranes; VII-107



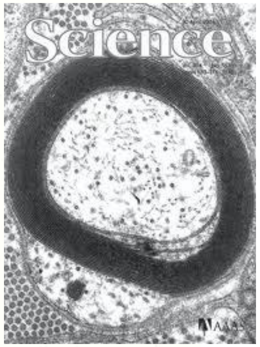


Figure 11. Scattering data (intensity vs angle 2θ) from retinal rods, the light transducing system of the eye. The bottom three traces are taken with conventional techniques (see text). The top trace is taken with the position-sensitive neutron detector.

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Two classic publications representing developments that spurred productive structural biology experiments at the HFBR

Nuclear Instruments and Methods 178 (1980) 543-554

Nuclear Instruments and Methods 178 (1980) 543–554

CENTROID FINDING METHOD FOR POSITION-SENSITIVE DETECTORS *

Veljko RADEKA and Robert A. BOIE
Brookhaven National Laboratory, Upton, New York 11973, U.S.A.

Received 26 June 1980

A new centroid finding method for all detectors where the signal charge is collected or induced on strips or wires, or on subdivided resistive electrodes, is presented. *The centroid of charge is determined by convolution of the sequentially switched outputs from these subdivisions or from the strips with a linear centroid finding filter.* The position line width is inversely proportional to $N^{3/2}$, where N is the number of subdivisions.

1. Introduction

The problem of accurate centroid finding of the charge collected or induced on discrete or continuous resistive electrodes appears in most applications of all ionization and electron multiplying position-sensitive detectors. The centroid is usually determined by a global continuous readout employing delay lines or charge division, fig. 1a. Alternatively, it could be determined by computation from the outputs of discrete strips or wires, fig. 1b. The global continuous readouts have the advantage of relative simplicity. Their main disadvantage stems from the fact that both the position line width and the position error (i.e., absolute integral nonlinearity) increases with the size of the detector, since the line width is determined as

$$\text{fwhm} \propto \frac{C_D^a l}{Q_s}, \qquad (1)$$

where

a = $\frac{1}{2}$ for position sensing on resistive electrodes, and for position sensing with delay lines $1/2 \leqslant a \leqslant 1$;
C_D = total readout electrode capacitance;
l = total length of the readout electrode;
Q_s = Charge induced or collected on the readout cathode.

* This research was supported by the U.S. Department of Energy: Contract No. DE-AC02-76CH00016.

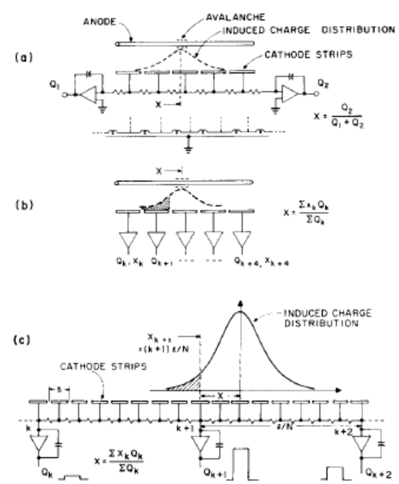


Fig. 1. Centroid finding. (a) Charge division and delay line position sensing (two outputs for the whole length of the detector). (b) "Amplifier per strip" or "center of gravity" method [1,6]. (c) Subdivided charge division. Charge outputs Q_k are determined by the position, shape and width of the induced charge distribution. Sample amplitudes are shown qualitatively. All amplifiers shown are "charge sensitive" with input impedance small compared to the resistance between adjacent amplifiers.

Nuclear Instruments and Methods 200 (1982) 533-545

Nuclear Instruments and Methods 200 (1982) 533–545
North-Holland Publishing Company

TWO-DIMENSIONAL HIGH PRECISION THERMAL NEUTRON DETECTOR *

R.A. BOIE, J. FISCHER, Y. INAGAKI, ** F.C. MERRITT, H. OKUNO *** and V. RADEKA
Brookhaven National Laboratory, Upton, New York 11973, U.S.A.

Received 12 January 1982

A position resolution of 1.3 mm (fwhm) and integral non-linearity of ±0.1% is achieved in a two-dimensional 18×18 cm² thermal neutron detector. The gas proportional detector operates at a moderate pressure (5–6 atm) with a ^{3}He–C_3H_8 mixture and at very low required avalanche gain (~30) by virtue of the high precision centroid finding position readout.

1. Introduction

Two-dimensional position sensitive detectors are being increasingly used in neutron diffraction experiments for determination of molecular and crystal structures in biology, solid state physics and polymer chemistry. Position sensitive detectors for neutrons in the wavelength range from 1.8 Å (~25 meV, i.e., "thermal neutrons") to about 8 Å (~1.2 meV, i.e., "cold" neutrons) require a high detection efficiency for neutrons and a low efficiency for background γ-rays, high uniformity of efficiency, good position resolution at counting rates of up to ~10^5 s^{-1}, high position accuracy, little scattering in the entrance window, and stable maintenance free operation over long periods of time.

Detectors built at BNL according to the original development reported previously [1] have been operated successfully as part of facilities for biological research at the High Flux Beam Reactor.

Recently, we have made some substantial improvements in all of the detector characteristics listed above. The advances which have made this possible are in two areas: (1) a new method has been developed for position sensing, and (2) new gas mixtures have been explored, allowing higher position accuracy and resolution at lower gas pressures. A new detector based on these advances is described in this paper.

Some basic considerations in the design of two-dimensional neutron detectors are given in ref. 1, where the choice of the neutron induced reaction and the detection method are discussed.

* This research was supported by the U.S. Department of Energy: Contract No. DE-AC02-76CH00016.
** On leave from Kyoto University, Kyoto, Japan.
*** Present address: Institute for Nuclear Study, University of Tokyo, Tanashi, Tokyo, Japan.

0167-5087/82/0000–0000/$02.5 © 1982 North-Holland

For quantitative neutron diffraction experiments, where position accuracy, uniformity of efficiency and stability of response are of utmost importance, gas proportional detector – properly applied – are the most suitable so far. Our neutron detectors are based on the ionization produced by the charged-particles from the reaction ^{3}He + n → ^{3}H + p + 0.764 MeV. Some alternative approaches are described in refs. 5, 6 and 7.

A principal problem of gas detectors, combined with conventional position readout methods, is that the high avalanche size (usually in the one picocoulomb range) required for good position resolution results in impairment of several important detector characteristics. As the gas gain and the avalanche size are increased, the space charge thus created causes a nonlinear energy response. This results in poor energy resolution and an overlap between amplitude distributions for gamma rays and neutrons, which precludes their separation. Furthermore, at high gas gains the nonuniformity of the gas gain over the detector area increases (for a given nonuniformity of parameters of the detector electrode geometry). This and the poor energy resolution make the attainment of a high uniformity of efficiency and of stable operation difficult.

We have resolved this problem by development of a much more sensitive position readout method which allows a much lower avalanche size – in the range of less than one tenth of a picocoulomb. With a total energy of 764 keV of the proton and triton released in the neutron induced reaction, the primary ionization in gas is ~3×10^4 ion pairs. The readout requires a gas gain of only about 20–30, where the adverse effects of charge multiplication and the space charge are negligible.

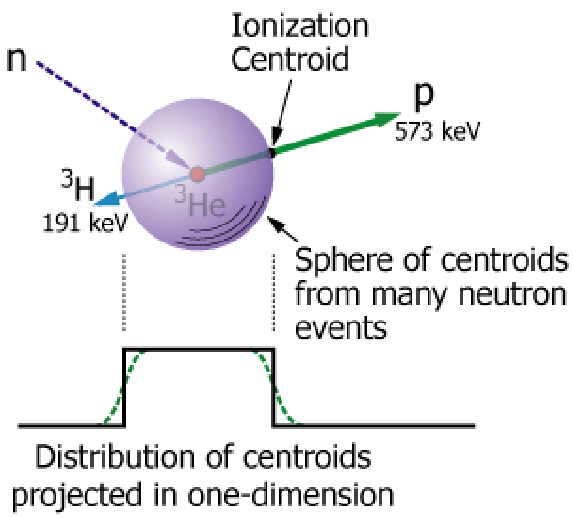
We have reported the high precision position sensing method previously [2]. The principle of this method is illustrated in fig. 1. In this method the centroid of charge induced on the position sensing electrode is determined by convolution of the sequentially switched

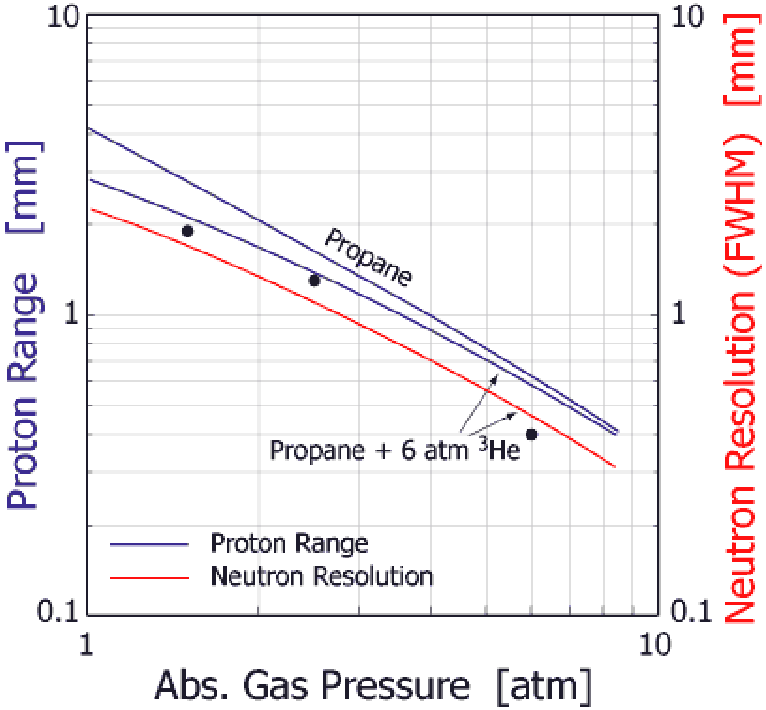
Thermal Neutron Detection in ^{3}He and Position Resolution Limit

$$n + {}^3He \rightarrow p + {}^3H + 764\ keV$$

↓

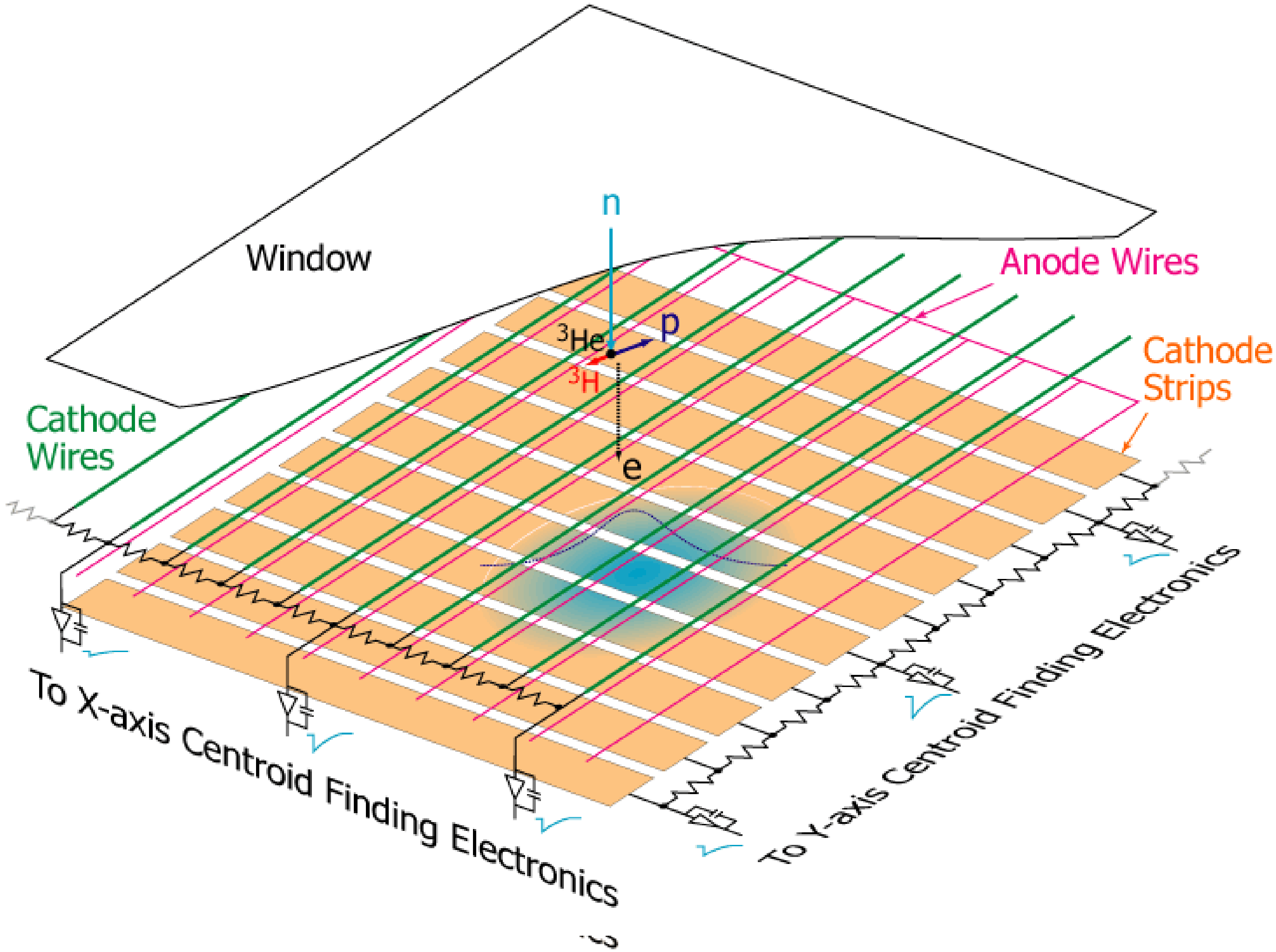
~25000 electron-ion pairs





FWHM ~ 0.8 proton range
(~4.2mm in 1 atm. propane)

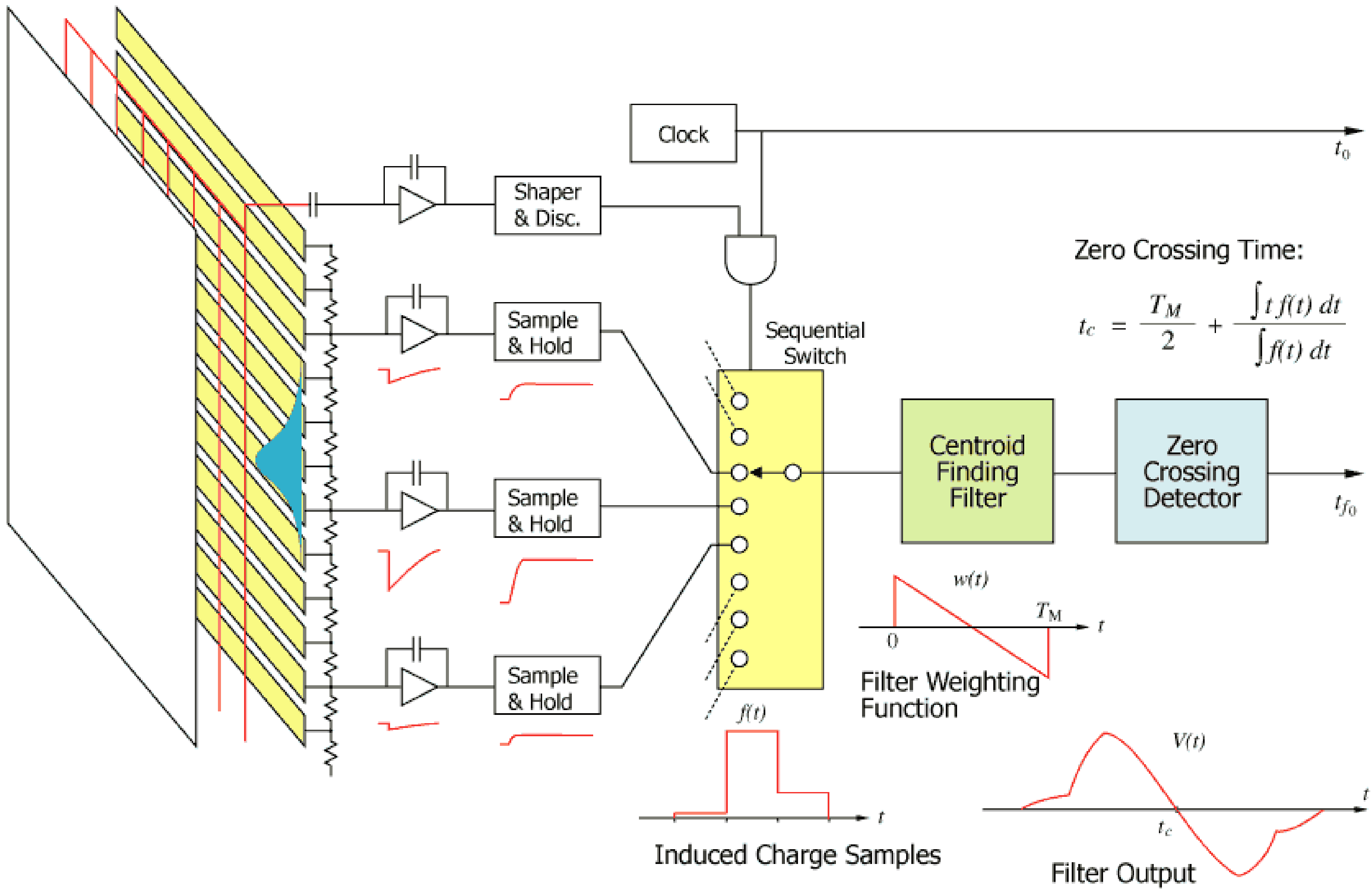
Position Encoding with Interpolating Cathode Strips



J.L. Alberi and V. Radeka, IEEE Trans. Nucl. Sci 23 (1976) 251-258

G.W. Fraser, E. Mathieson and K.D. Evans, Nucl. Instrum. & Meth. 180 (1981) 269-279

Analog Centroid Finding System

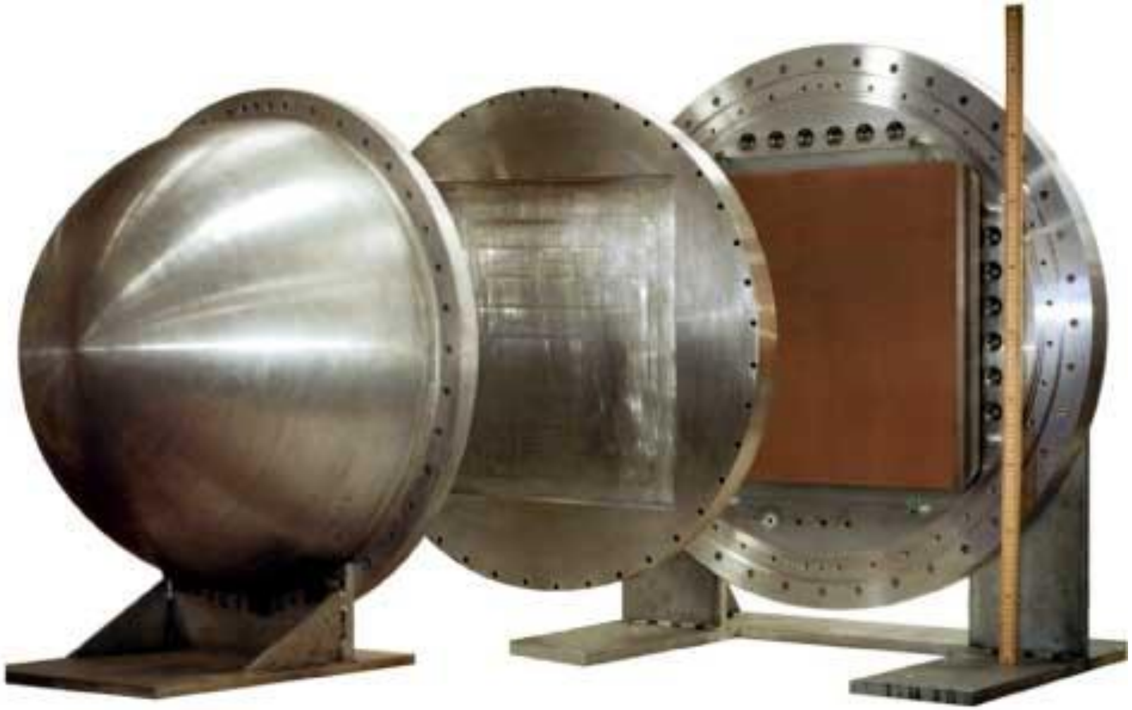


V. Radeka and R.A. Boie, Nucl. Instrum. & Meth. 178 (1980) 543-554

Large Area 50cm×50cm Detector for Small-Angle Neutron Scattering

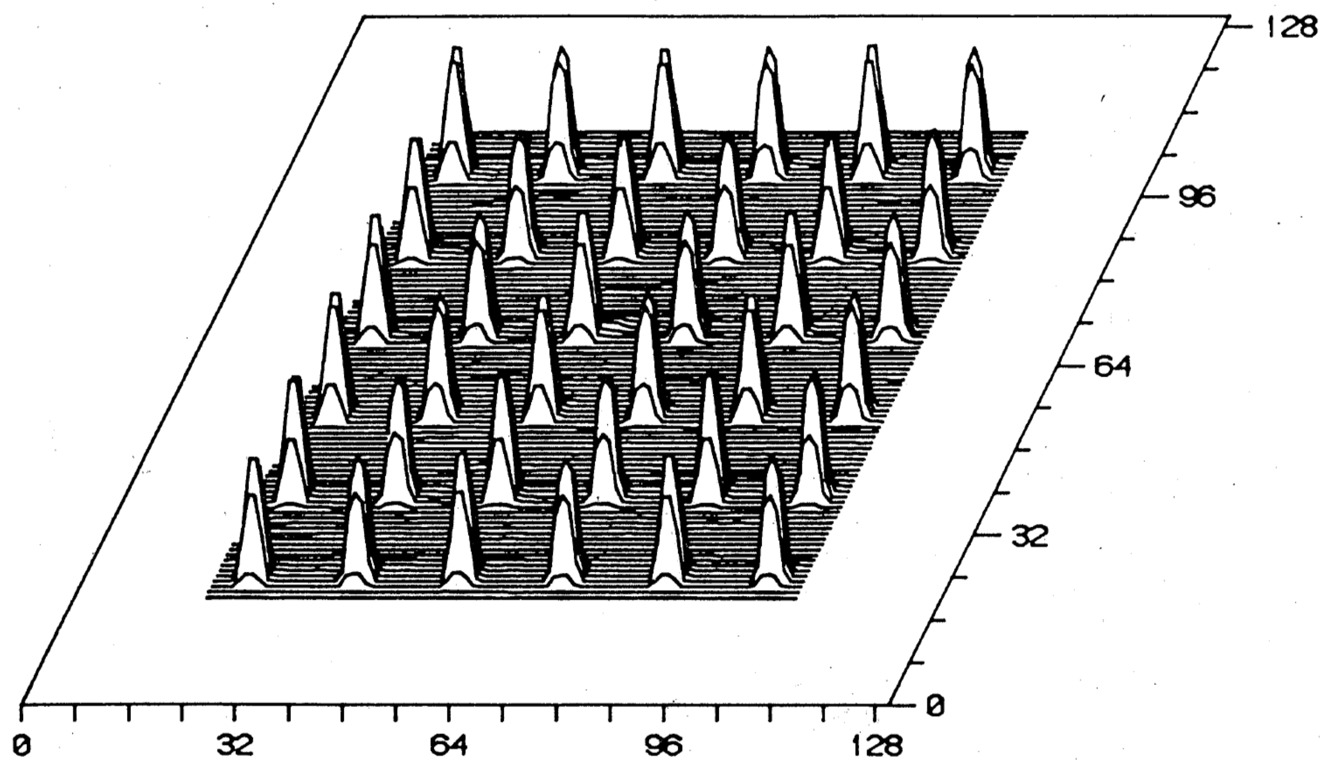
- Developed for Small-Angle Neutron Scattering (SANS)
- 4 atm. ^{3}He + 1.8 atm Propane
- 2mm FWHM position resolution
- Absolute position stability 50μm

Beam Line H9B
at the HFBR



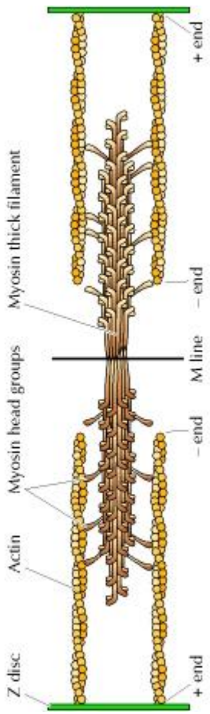
Outer window dome,
Inner window, and
Multi-wire electrodes

Large Area 50cm×50cm Detector had Unprecedented Positional Accuracy

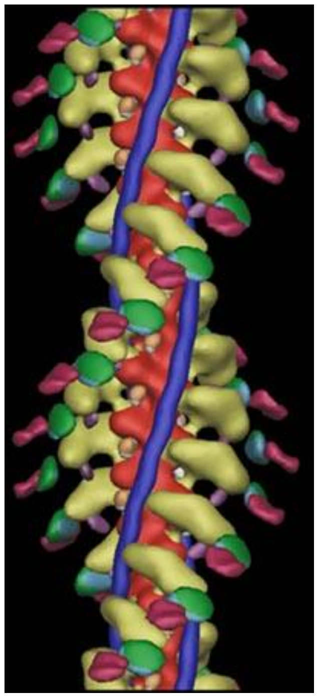


Response of the 50cm by 50cm detector to a raster scan of 36 primary neutron beams, indicating the excellent position stability of the detector design and the centroid finding filter encoding system. This detector absolute positional accuracy was better than 50 microns, ***unprecedented at the time***, and enabling data-taking over extended periods of time (several days), with no electronic drift.

The Exquisite Counting Stability of the 50x50cm^2 Detector Made it Possible to Study Conformational Changes in Muscle Myosin

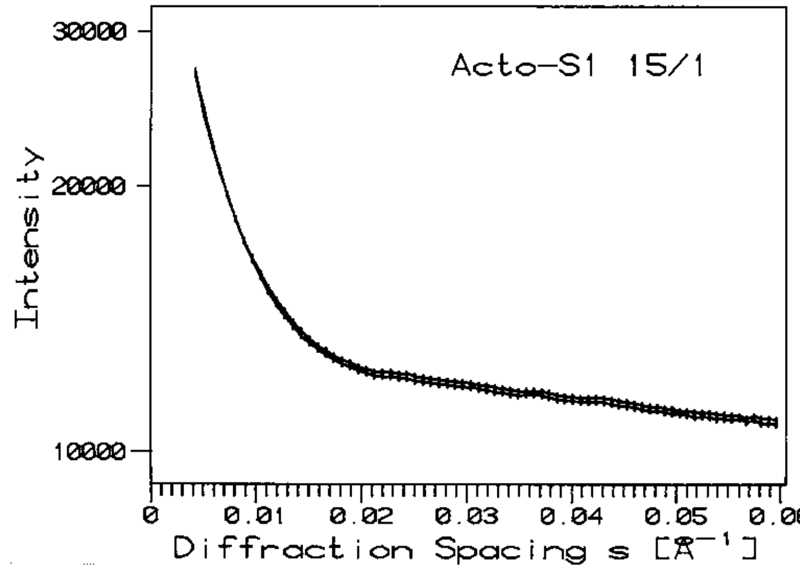


Architecture of Muscle

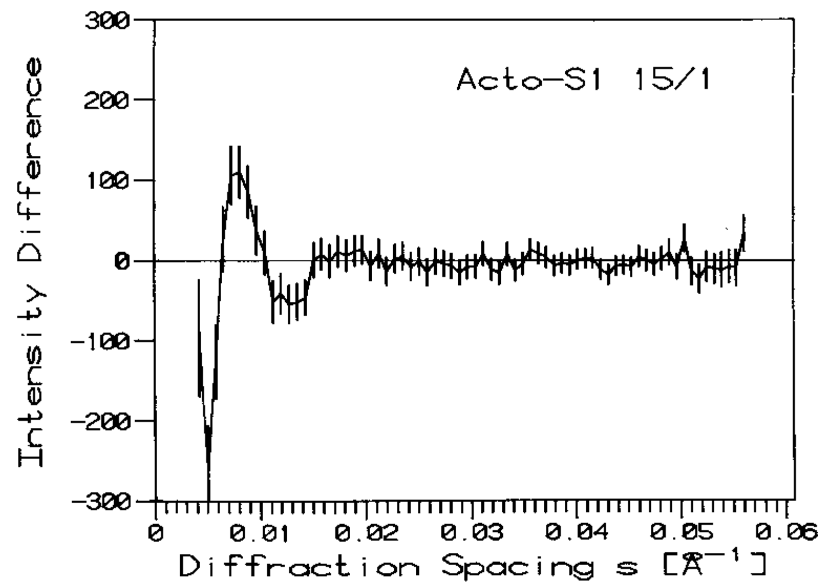


Decorated F-Actin

Two S1 on F-actin samples arrested at different states of the enzymatic cycle of the power stroke

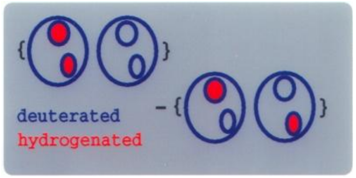


Difference intensity is amenable to interpretation by model building

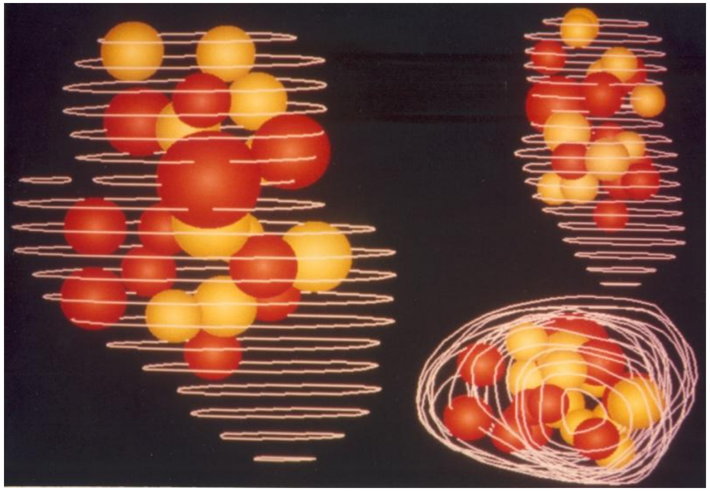


PMG Curmi, D. B. Stone, DK Schneider, JA Spudich, and RA Mendelson. Comparison of the Structure of Myosin Subfragment 1 Bound to Actin and Free in Solution. J. Mol. Biol. 203, 781-798 (1988).

The 50cm Detector was a Workhorse in the Early Days of Ribosome Structure Determination by the Yale Groups of Don Engelman and Peter Moore



Yale Triangulation Method



Complete 21 protein map of 30S ribosomal subunit

MS Capel, DM Engelman, BR Freeborn, M. Kjeldgaard, JA Langer, V Ramakrishnan, DG Schindler, DK Schneider, BP Schoenborn, IY Sillers, S Yabuki, and PB Moore
A Complete mapping of the Proteins in the Small Ribosomal Subunit of *Escherichia coli*
Science (1987) 238, 1403-1408

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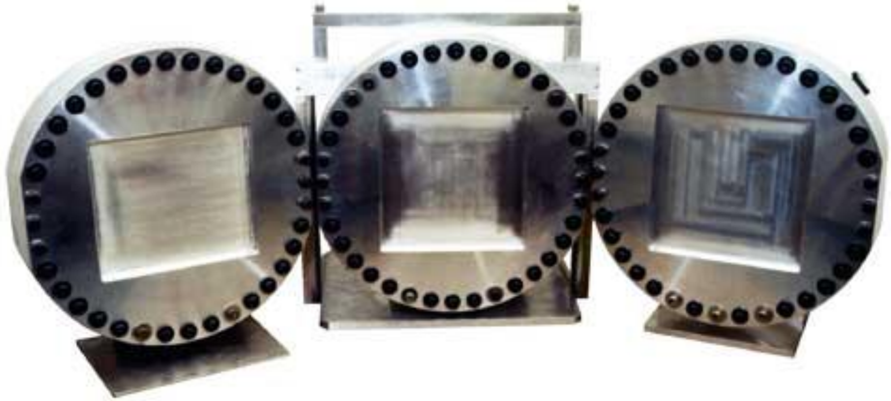
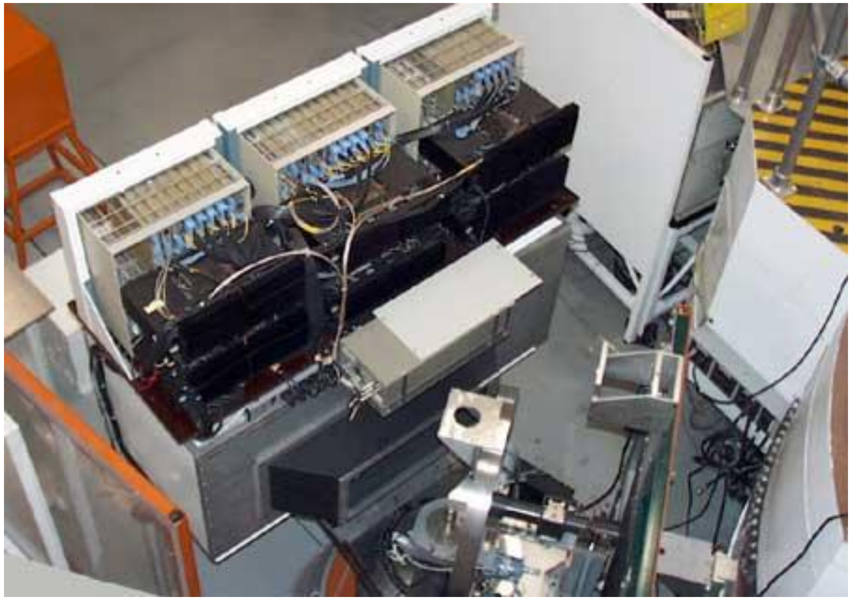
High Precision 20cm×20cm Detectors for Neutron Protein Crystallography

- Developed for SANS and LANS, particularly protein crystallography
- 6 atm. ^3He + 2.5 atm. Propane
- Position resolution ~ 1.3mm FWHM
- 3 detectors along an arc for greater angular coverage (with gaps)

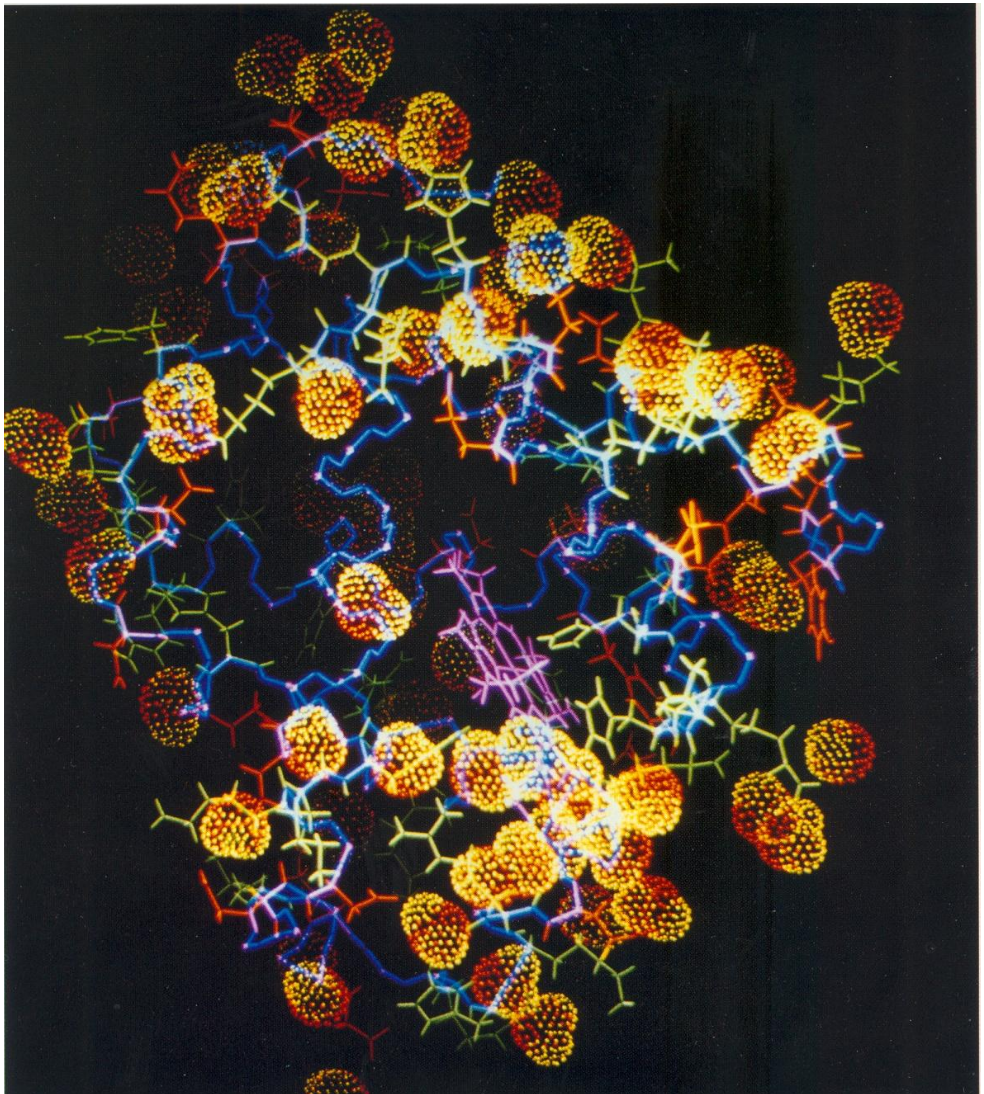


Front view of array of three 20×20 cm^2 detectors



Array of three 20×20 cm^2 detectors at H3 of HFBR

Neutron Protein Crystallography, the Ultimate Test of Detector Stability Over Months

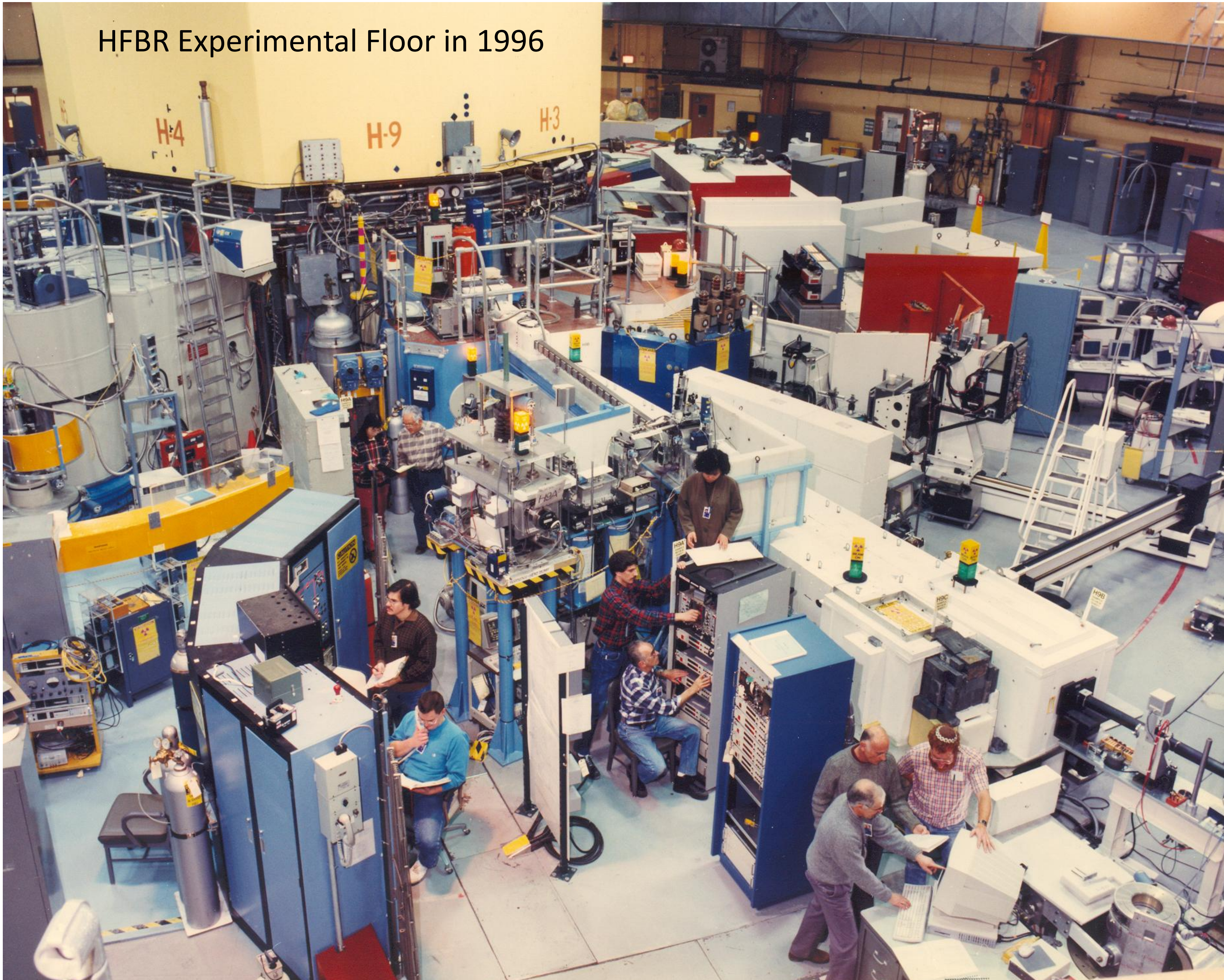


Model of CO myoglobin showing 87 surface water molecules and 5 ions.

Max Perutz, Benno Schoenborn, and DKS in 1986

Xiadong Cheng and B. Schoenborn
Hydration in Protein Crystals.
A Neutron Diffraction Analysis of
Carbonmonoxymyoglobin
Acta Crystallographica (1990) B46, 195-208

HFBR Experimental Floor in 1996



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120º Position-Sensitive ^{3}He Neutron Detectors

<u>LANSCE, LANL</u>

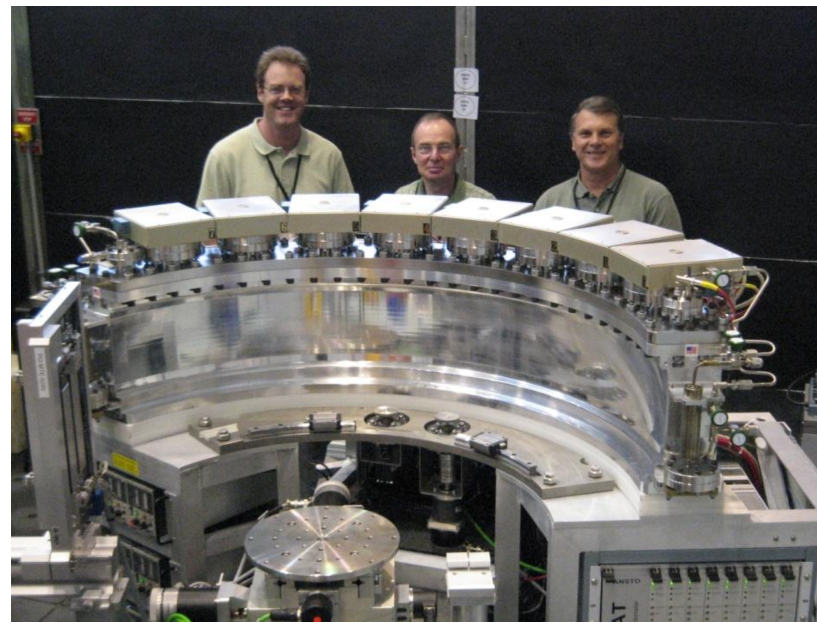
Installation: Jan 2002

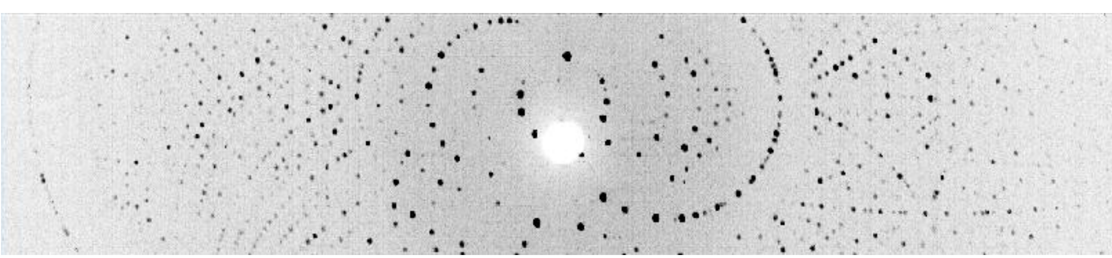
Detector is major component in the Protein Crystallography Spectrometer

<u>ANSTO, Australia</u>

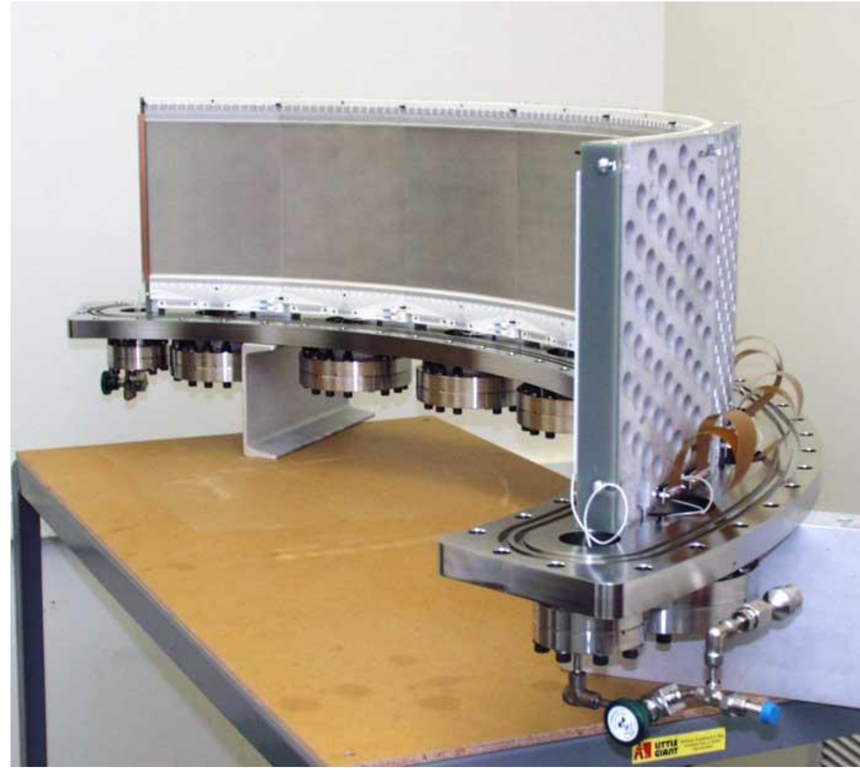
Installation: January 2007

Detector is a major component of the HIPD, or High Intensity Powder Diffractometer

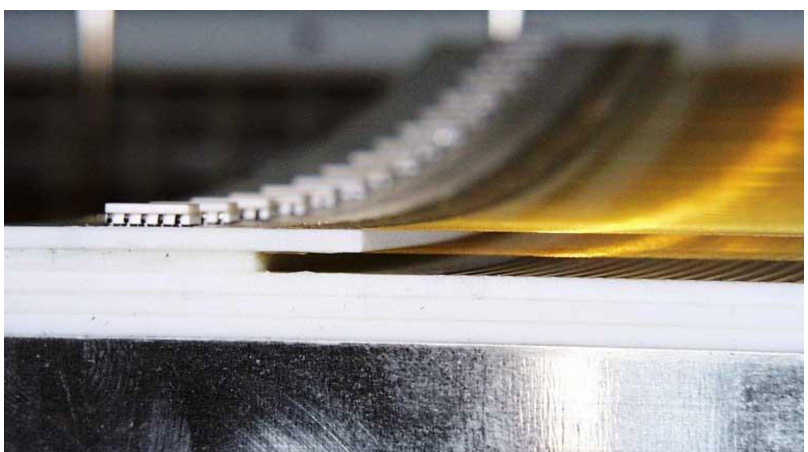




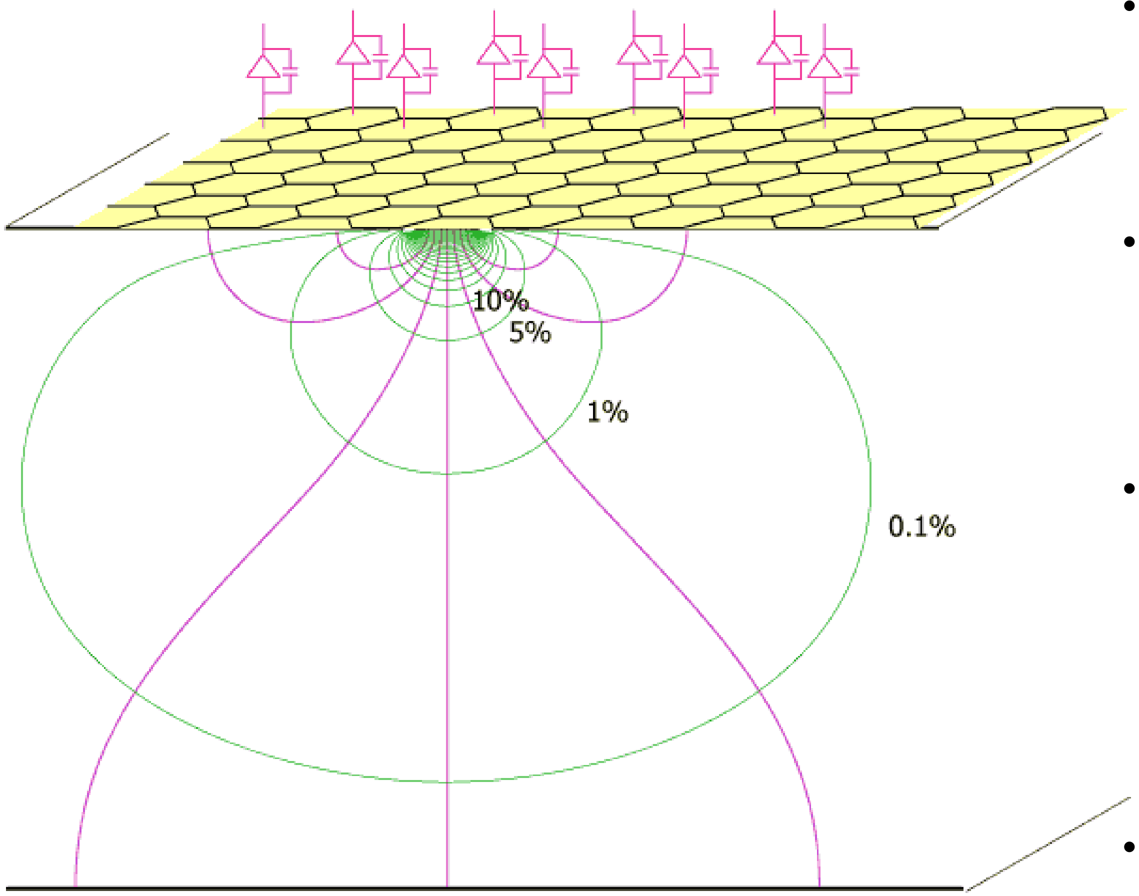
Detector for protein crystallography at Los Alamos Neutron Science Center (LANSCE)



- 120 horizontal and 15 vertical coverage @ 70cm radius of curvature
- Position resolution < 1.5mm FWHM
- Counting rate > 10^6 /s
- Digital centroid finding modules

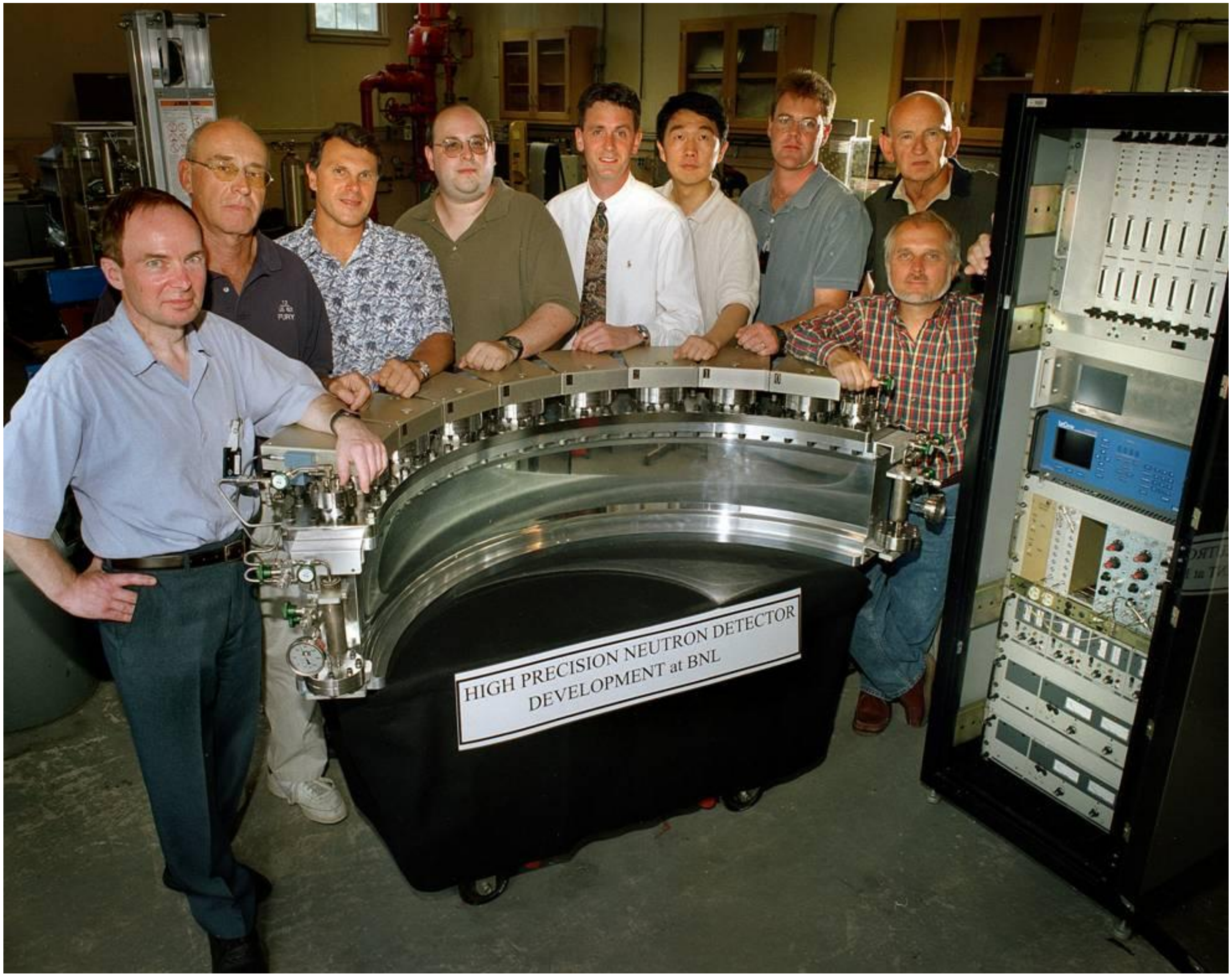


Future Directions: 2D Pixel Readout in Ionization Mode



- Ultra high count rate capability: ~10^5 /s per pixel, >10^8 /s per detector
- No gas amplification:
  - No aging effect
  - Stability and reliability
- Flexible geometry:
  - Pixel dimension: ~ 1 – 5mm
  - Parallax reduction
  - Large area, complex geometry possible
- Reliant on development of low noise ASICs

Neutron Detector R&D in Instrumentation



Left to right:

Graham Smith
Don Mackowicki
Neil Schaknowski
Jack Fried
George
Bo Yu
Joe Mead
Veljko Radeka
Joe Harder